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(54) **ELECTRONIC SAFE/ARM SYSTEM AND METHODS OF USE THEREOF**

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See application file for complete search history.

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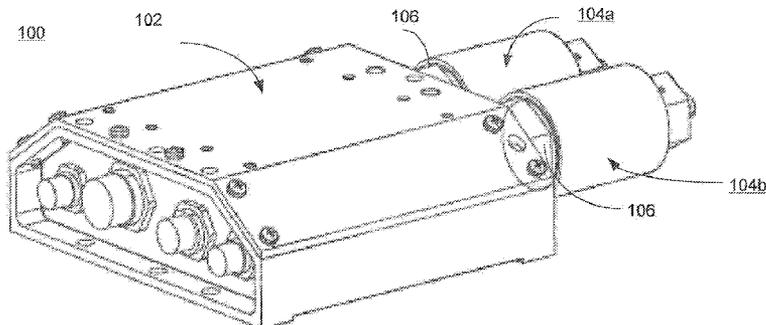
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(57) **ABSTRACT**

An ordnance firing system is disclosed that includes a reusable electronics module and an ordnance module, each enclosed in a separate, sealed housing. The electronics module housing encloses firing electronics for electrically triggering initiation of a detonator in the ordnance module. The electronics module detachably connects to the ordnance modules via a connector which extends away from the electronics module housing. The housing of the ordnance module is constructed to be blast-resistant to prevent detonation of the detonator from rendering the electronics module inoperable.

**7 Claims, 7 Drawing Sheets**



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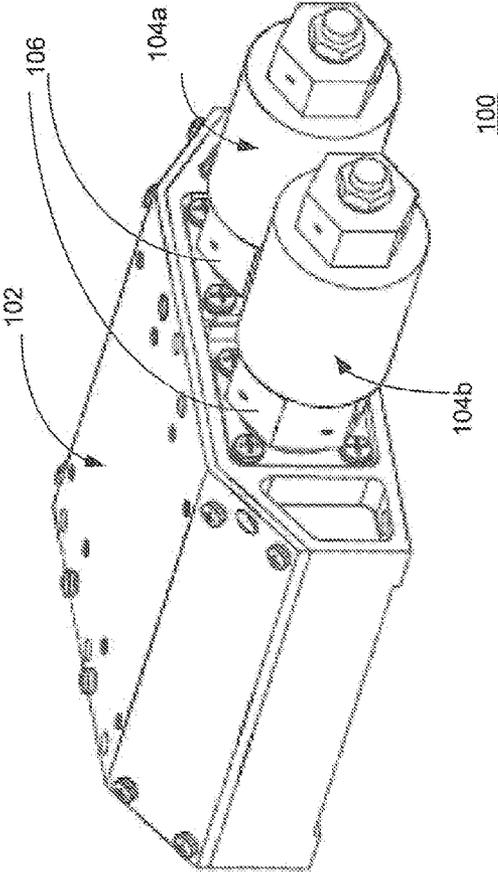
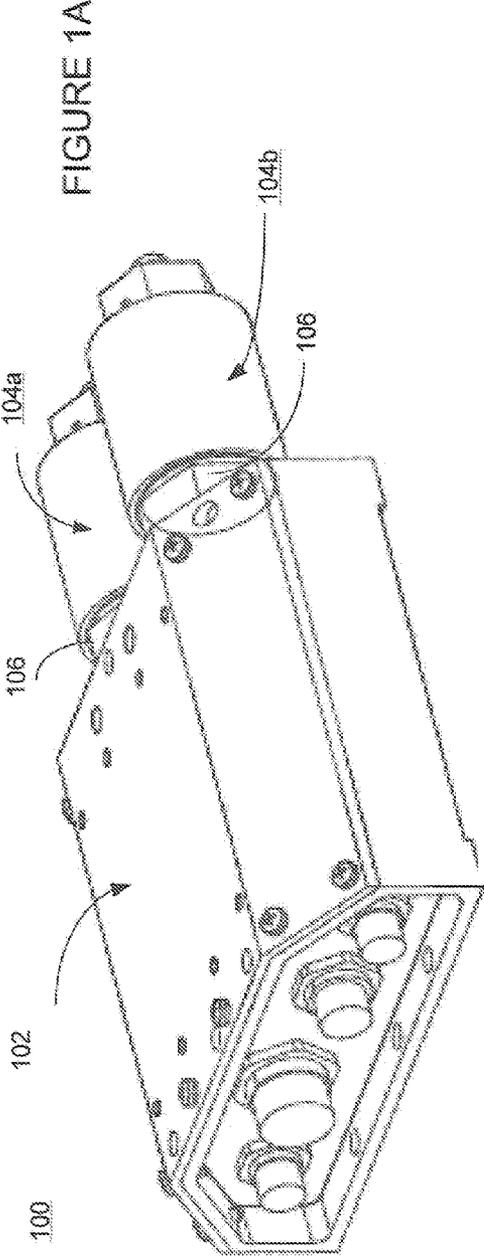
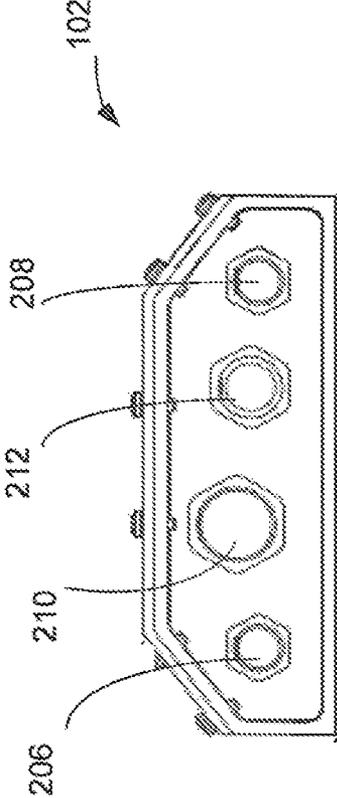
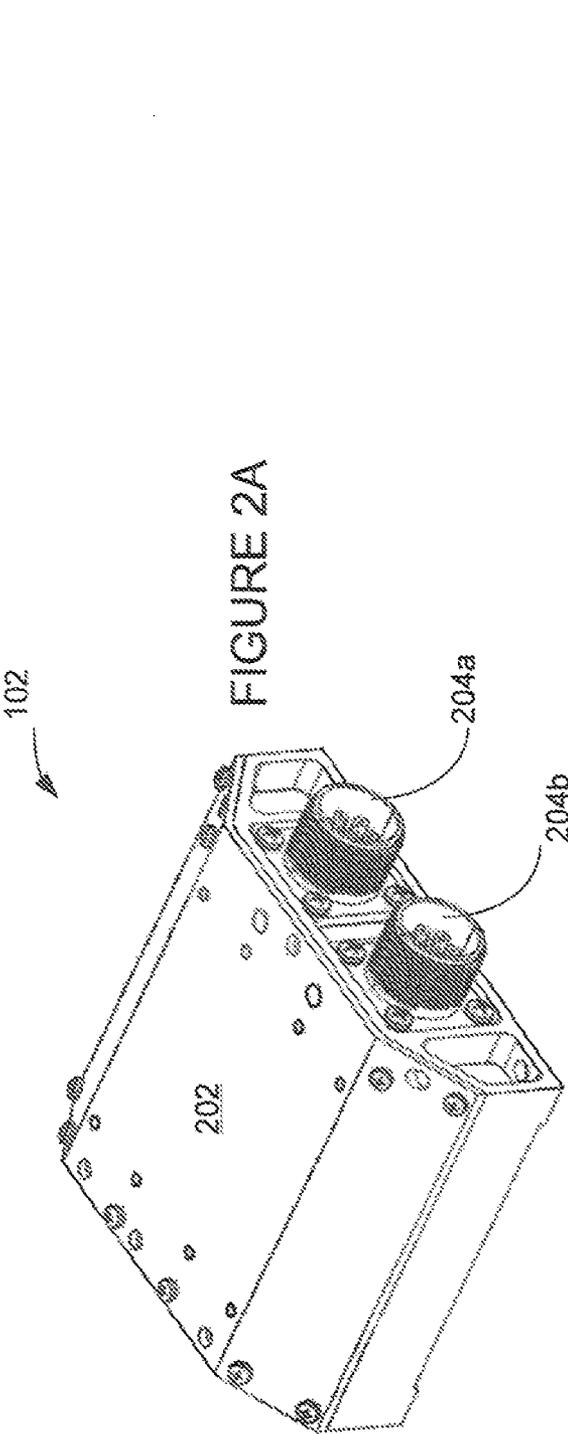


FIGURE 1B



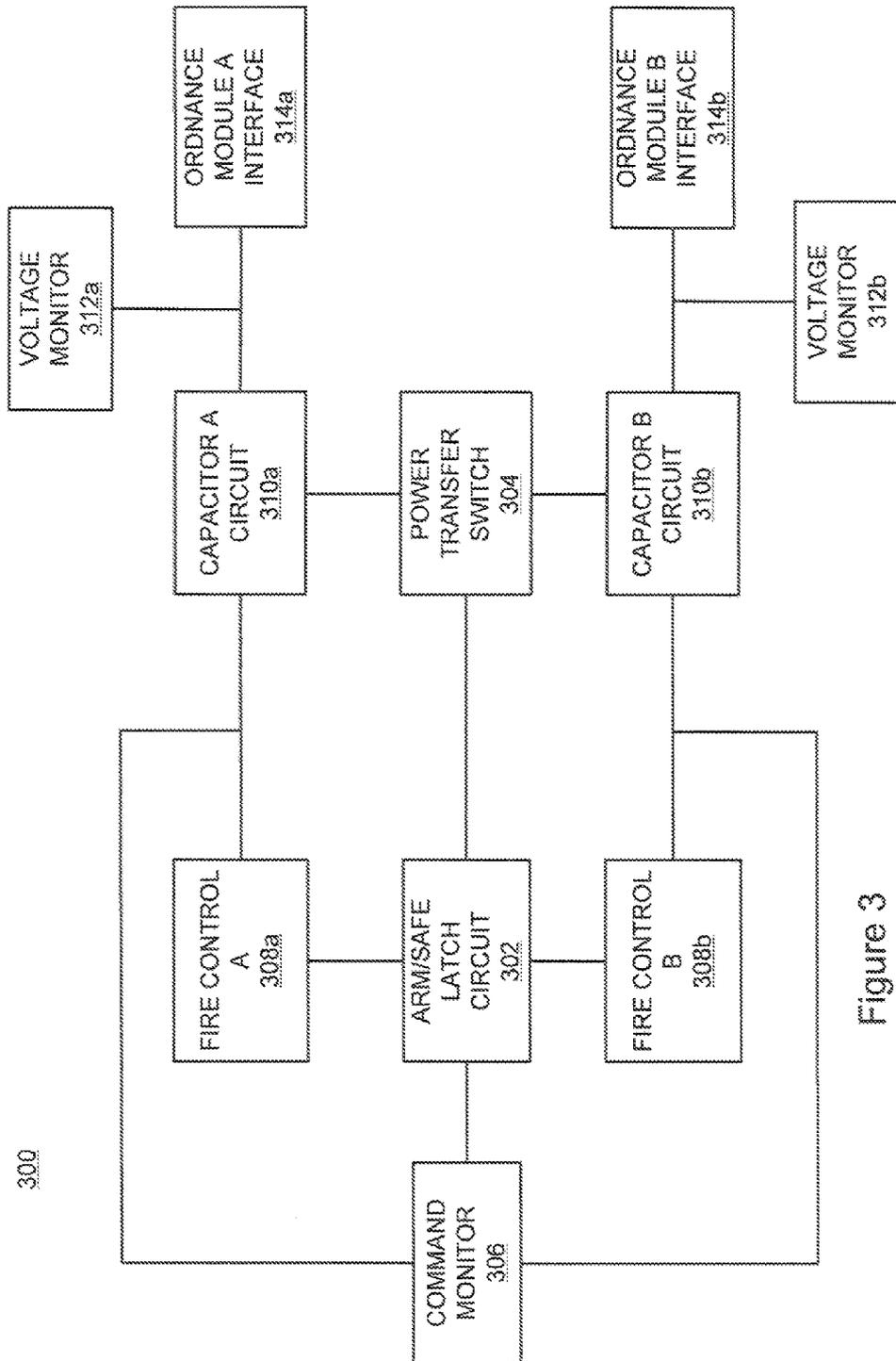
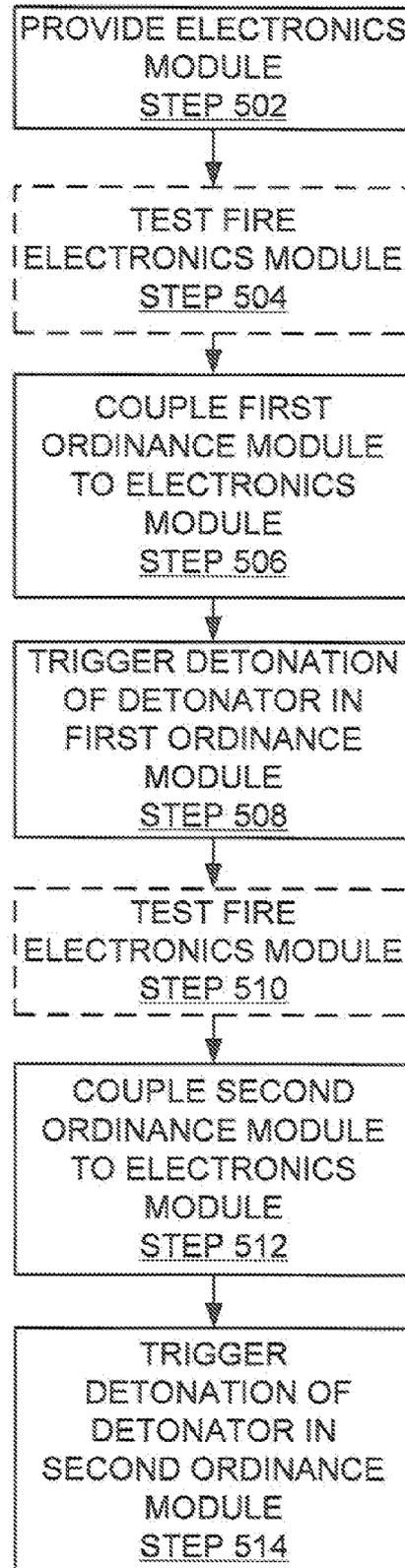


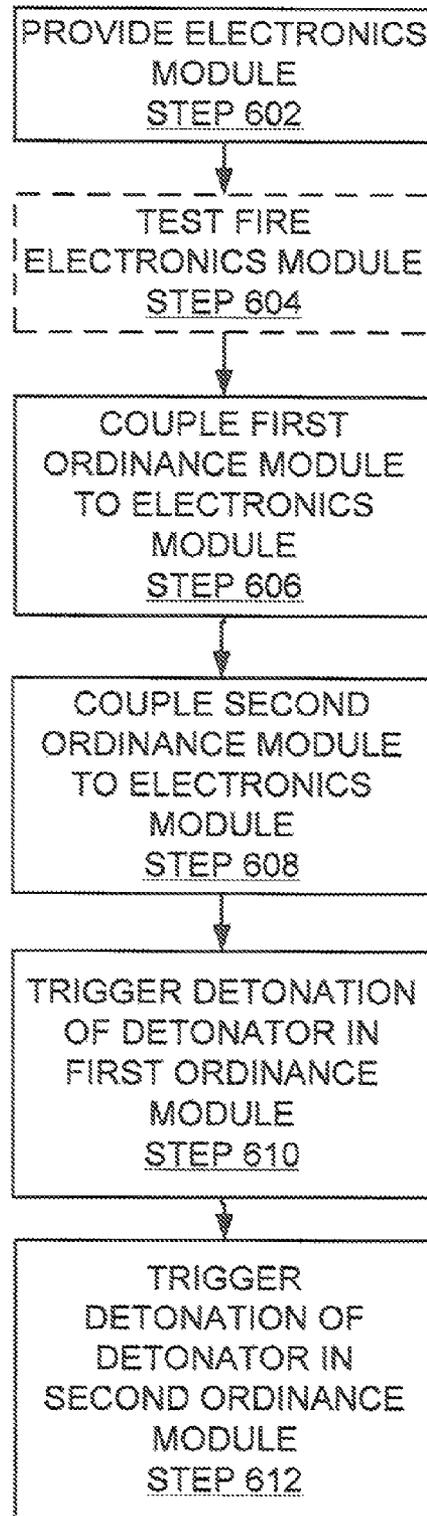
Figure 3





500

FIGURE 5



600

FIGURE 6

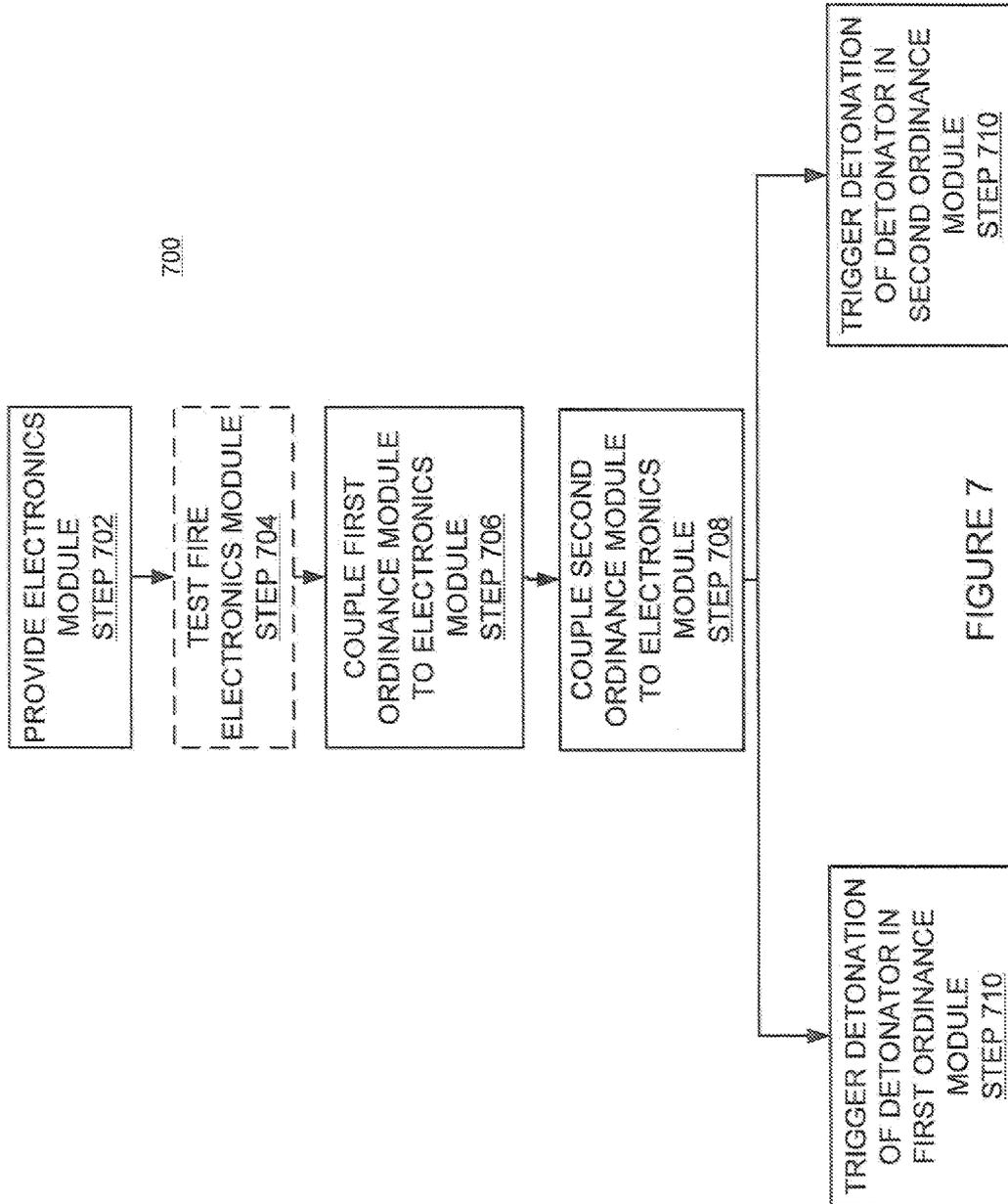


FIGURE 7

## ELECTRONIC SAFE/ARM SYSTEM AND METHODS OF USE THEREOF

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. patent application Ser. No. 12/778,046, filed on May 11, 2010. The entire teachings of the above application is incorporated herein by reference.

### BACKGROUND OF THE INVENTION

Various electronic safe/arm devices (ESAD's) are known. A typical ESAD includes two portions, an electronics portion and an explosive ordnance portion that houses the detonator assembly. In most ESADs, the two portions are enclosed in a single housing. As a result, use of such an ESAD will invariably destroys the entire device. Single housing ESADs also suffer from an inability to be safely and easily transported, disposed of if unused, or have their electronics tested, as the power electronics are intrinsically connected to the detonators, increasing the risk of inadvertent initiations.

To mitigate certain of the shortcomings of traditional ESADs, more recent ESADs have been developed that maintain the electronics portion of the ESAD in a separate housing to which an ordnance module can later be attached. This advance allows for the easy transport and safe testing of ESAD electronics, but it failed to enable repeated uses of the electronics, as they still are usually damaged or destroyed upon a single use.

### BRIEF SUMMARY OF THE INVENTION

To overcome this shortcoming and others, according to one aspect the invention relates to a firing system that includes a reusable electronics module. The firing system includes an electronics module and an ordnance module. The electronics module includes a first housing that encloses firing electronics for electrically triggering initiation of a detonator. The electronics module also includes a connector that extends away from the first housing for detachably mechanically and electrically connecting the electronics module to the ordnance module.

The ordnance module includes a second, blast-resistant housing that encloses a detonator. The detonator, in one embodiment, is an explosive foil initiator, also known as a slapper detonator. The ordnance module housing is sufficiently blast-resistant that detonation of the detonator does not render the electronics module connected thereto inoperable or unable to connect to a second ordnance module. The ordnance module also includes a connector that extends away from the proximal end of the ordnance module housing. The ordnance module connector is configured to mate with the electronics module connector.

The connectors extending from the electronics module and ordnance module housings, in one embodiment, are complementary multi-pin connectors compliant with US military standards MS3106-16 or SAE-AS31061. A plurality of pins of the multi-pin connectors are used for carrying, in parallel, current to the ordnance module, and a plurality of the pins are used for carrying, in parallel, current back from the ordnance module, to provide a low impedance connection. In one embodiment, the connectors are threaded. The ordnance module includes, in one embodiment, a threaded, rotatable

hex coupling nut for easy attachment and securing of the ordnance module connector to the electronics module connector.

In one embodiment, the electronics module includes a second electronics module connector for mating to a second ordnance module, such that the electronics module can be coupled to two ordnance modules concurrently. In such embodiments, the electronics module can be configured to trigger both ordnance modules simultaneously, or one after the other.

According to another aspect, the invention relates to a method of using a firing system. The method includes providing an electronics module that encloses firing electronics within a first housing. An ordnance module is then coupled to the electronics module via a connector extending away from the electronics module housing. The ordnance module includes a blast-resistant housing that encloses a detonator. The detonator, in one embodiment, is an explosive foil initiator, also known as a slapper detonator. The ordnance module housing is sufficiently blast-resistant that detonation of the detonator does not render the electronics module connected thereto inoperable or unable to connect to a second ordnance module. The method further includes triggering initiation of the detonator without the resulting detonation substantially damaging the electronics module.

In certain embodiments, the method includes coupling a second ordnance module to the electronics module. In one embodiment, the second ordnance module is coupled to the electronics module prior to initiation of the first ordnance module. The ordnance modules may then be initiated in substantially simultaneously or at separate times. In other embodiments, the second ordnance module is connected to the electronics module subsequent to the initiation of the detonator in the first ordnance module. The second ordnance module may be coupled to the same electronics module connector used to connect the first ordnance module to the electronics module, or it may be coupled to a different electronics module connector. The electronics module then triggers initiation of the detonator in the second ordnance module.

In one embodiment, the method includes test firing the firing electronics prior to coupling the ordnance module to the electronics module. In another embodiment, the method includes test firing the firing electronics subsequent to initiating the detonator in a first ordnance module and prior to initiating a second detonator in a second ordnance module.

According to another aspect, the invention relates to an ordnance module that includes a blast-resistant housing. The ordnance module housing is sufficiently blast-resistant that detonation of the detonator does not render an electronics module connected thereto inoperable or unable to connect to a second ordnance module. The ordnance module housing encloses a detonator. The detonator, in one embodiment, is an explosive foil initiator, also known as a slapper detonator. The ordnance module also includes a connector for mechanically and electrically connecting the ordnance module to an electronics module configured to trigger initiation of the detonator. The connector, in one embodiment, is a standard multi-pin connector. A plurality of the pins of the multi-pin connector carry current in parallel to the detonator to trigger its initiation. According to one embodiment, the ordnance module includes a port for holding a detonating cord. The ordnance module housing is configured to direct the explosive force of the detonator to trigger explosion of the detonating cord to trigger at least one detonation remote from the ordnance module.

## BRIEF DESCRIPTION OF THE DRAWINGS

The methods and systems may be better understood from the following illustrative description with reference to the following drawings in which:

FIGS. 1A and 1B are isometric views of a firing system according to an illustrative embodiment of the invention.

FIG. 2A is an isometric view of the electronics module of the firing system of FIGS. 1A and 1B.

FIG. 2B is a rear view of the electronics module of the firing system of FIGS. 1A and 1B.

FIG. 3 is a functional block diagram of the electronics module of the firing system of FIGS. 1A and 1B.

FIG. 4A is an isometric view of the ordnance module of the firing system of FIGS. 1A and 1B.

FIG. 4B is a cross-sectional view of the ordnance module of the firing system of FIGS. 1A and 1B.

FIG. 5 is a flow chart of a method of using a firing system, similar to that depicted in FIGS. 1A and 1B, though only having a single connector for connecting to one ordnance module at a time.

FIG. 6 is a flow chart of a second method of using a firing system, such as the firing system of FIGS. 1A and 1B.

FIG. 7 is a flow chart of a third method of using a firing system, such as the firing system of FIGS. 1A and 1B.

## DETAILED DESCRIPTION OF THE INVENTION

To provide an overall understanding of the invention, certain illustrative embodiments will now be described, including systems for triggering initiation of explosives and methods of use thereof. However, it will be understood by one of ordinary skill in the art that the systems and methods described herein may be adapted and modified as is appropriate for the application being addressed and that the systems and methods described herein may be employed in other suitable applications, and that such other additions and modifications will not depart from the scope thereof.

FIGS. 1A and 1B are isometric views of a firing system 100 according to one embodiment of the invention. The firing system 100 includes an electronics module 102 and at least one ordnance module 104. The firing system 100, for example, includes two ordnance modules 104. Alternative embodiments can include only a single ordnance module 104, or three or more ordnance modules 104. The ordnance modules 104 may be triggered substantially simultaneously, or separated in time. In embodiments with three or more ordnance modules 104, two or more ordnance modules 104 may be triggered substantially simultaneously while at least one additional ordnance module 104 may be triggered before or after such triggering event.

The electronics module 102 and the ordnance modules 104 are enclosed in separate housings. They are electrically and mechanically coupled by complimentary connectors 106 extending from their respective housings. The complimentary connectors 106 are preferably multi-pin connectors compliant with US military standards MS3106-16 or SAE-AS31061. The opposing connectors 106 are preferably threaded for easy, secure connection, without requiring specialized tools. The opposing connectors 106 are described further in relation to FIGS. 2A, 4A, and 4B.

The housings of the ordnance modules 104 are designed to be sufficiently blast-resistant that detonation of a detonator within an ordnance module 104 does not substantially damage the electronics module housing, the electronics enclosed therein, or the portion of the connector 106 extending away from the electronics module 102 that mates with a connector

portion extending from the ordnance module 104. In certain embodiments, the electronics module 102 may also have a blast-resistant construction to help prevent damage resulting from the detonation of the ordnance module 104 detonator.

The electronics module 102, the ordnance module 104, and methods of using the firing system are described further in relation to FIGS. 2-7.

FIG. 2A is an isometric view of the electronics module 102 of the firing system 100 of FIGS. 1A and 1B, according to an illustrative embodiment of the invention. As depicted in FIG. 2A, the electronics module includes a housing 202 and two male MIL-STD connectors 204a and 204b (each referred to generally as a "male connector 204") extending away from the housing 202. In one embodiment, the housing 202 is constructed from aluminum. While, as described below, the ordnance modules 104 are constructed to be sufficiently blast-resistant to reduce the explosive force directed towards the electronics module 102 resulting from triggering a detonator enclosed therein, the provision of a blast-resistant electronics module housing 202 further ensures the survival of the electronics enclosed within the housing 202.

Each male connector 204 includes multiple pins to carry a triggering current to and from the ordnance module 104. That is, each male connector 204 includes multiple pins for carrying a triggering current to an ordnance module 104 and multiple pins for receiving the triggering current back from the ordnance module 104. The use of multiple pins provides a reduced-impedance connection to ensure sufficient current to initiate the ordnance module detonator. The exterior of each male connector 204 is threaded for easy and secure mechanical connection of the male connectors 204 to a corresponding female connector 404 extending from ordnance module 104 (depicted in FIGS. 4A and 4B). Note that in alternative embodiments, the connectors extending away from the electronics module 102 are female connectors and the connectors extending from the ordnance modules 104 are male connectors.

In an alternative implementation, the electronics module 102 includes an external user interface via which a user can initiate diagnostic testing of the electronics module as well as receive the results of such a test. For example, the electronics module 102 may include an external test button for initiating a test sequence. The output may be provided by any suitable means known in the art. For example, the results of the test may be output by initiating illumination of one or more light emitting diodes (LEDs). For example a green LED may be illuminated if the test was successful, whereas a red LED may be illuminated if the test fails. Alternatively, the electronic device may indicate the results of the test audibly, via outputting of one or more beeps, tones, or other sounds associated with the various possible test results.

FIG. 2B is a rear view of the electronics module 102. The electronics module 102 includes four rear ports 206, 208, 210, and 212 for exchanging data with a control device as well as receiving power to trigger initiation of ordnance modules. Rear port 206, referred to as the Fire A Input Port 206, receives a signal governing the triggering of an ordnance module 104a coupled to connector 204a. Rear port 208, referred to as the Fire B Input Port 208, receives a signal governing the triggering of an ordnance module 104b coupled to connector 204b. In alternative embodiments, the electronics module 102 includes a single trigger data port which receives a signal encoding instructions, to trigger the ordnance modules 104 attached to male connectors 204a and 204b. The signal may be coded to instruct the electronics module 102 to trigger both ordnance modules 104 simultaneously, to trigger a single one of the ordnance modules 104,

or to trigger the ordnance modules according to a timed sequence. Rear port **210**, referred to as the Power, Command, and Monitor Port **210** is configured to receive power, to receive data signals instructing the electronics module to arm one or both ordnance modules or to enter a safe mode with respect to either or both ordnance modules, and to pass status data back from the electronics module **102** to the control device. Status data, in one implementation includes the voltages stored on firing capacitors, data indicating whether either ordnance module is armed, and data reporting back whether received commands have been executed. In one implementation, the Power, Command, and Monitor Port **210** also receives, signals for causing the electronics module **102** to conduct one or more diagnostic testing procedures. Rear port **212**, referred to as the ARM port **212**, is configured to receive both an ARM plug and a SAFE plug. When the SAFE plug is inserted into the ARM port **212**, current does not flow into the electronics module **102**. Placing the ARM plug into the ARM port **212** completes the power delivery circuit, enabling current to flow into the electronics module **102**. In practice, the SAFE Plug is inserted into the ARM port **212** while connecting ordnance modules **104** to the electronics module **102** to avoid inadvertent initiations. The ARM plug is then inserted to enable arming of the ordnance modules **104**.

FIG. **3** is a functional block diagram of an illustrative set of electronics components **300**, suitable for use in electronics module **102**, according to one embodiment of the invention. The electronics components **300** are for the most part standard firing system electronics known to one of ordinary skill in the art. However, in contrast to conventional firing systems, the electronics components **300** are enclosed in their own, sealed housing, apart from the detonator the electronics are designed to trigger. The electronics module **102** is also intended for use with blast-resistant ordnance modules **104**, described above, allowing the electronics module **102** to survive detonation of an ordnance module **104**. To take advantage of this feature, the electronics components **300** include certain duplicate components to enable sequential detonation of multiple ordnance modules **104**.

More specifically, the electronics components **300** include an Arm/Safe Latch Circuit **302**, a Power Transfer Switch **304**, and a Command Monitor **306**. In addition, the electronics components **300** includes separate triggering components for each of the ordnance modules **104** to which it can be concurrently connected. For each ordnance module **104**, the electronics components **300** include a Fire Control Circuit **308**, a Capacitor Circuit **310**, a Voltage Monitor **312**, and an Ordnance Module Interface **314**. As electronics module **102** is configured for concurrent coupling to two ordnance modules **104**, electronics components **300** includes Fire Control Circuits **308a** and **308b**, Capacitor Circuits **310a** and **310b**, Voltage Monitors **312a** and **312b**, and Ordnance Modules Interfaces **314a** and **314b**.

In general, a detonation has two phases: an arm phase and a trigger phase. The arm phase is initiated upon the Arm/Safe Latch Circuit **302** receiving a signal from a control device via the Power, Command, and Monitor Port **210** to arm one or both of the ordnance modules **104a** and **104b**. Upon receipt of the arm signal, the Power Transfer Switch **304** transfers power to high a voltage firing capacitor in the corresponding Capacitor Circuit(s) **310a** or **310b**. The capacitor is charged to a range of 700V to 1500V DC. Each Capacitor Circuit **310a** and **310b** includes amplifiers to increase the voltage received via the Power, Command, and Monitor Port **210** to the necessary voltage needed to charge the capacitors. The corresponding Voltage Monitor(s) **312a** and **312b** monitor the voltages on the capacitors and output the voltage back to the

control device via the Power, Command, and Monitor Port **210**. In the safe mode, the Arm/Safe Latch Circuit **302** prevents charging of capacitors in the Capacitor Circuits **310a** and **310b**.

Upon the capacitors reaching their desired voltage level according to the Voltage Monitors **312a** and **312b**, the control device may issue a fire command via the Fire A Input Port **206** and/or the Fire B Input Port **208** to start the trigger phase. Upon receiving such a signal, Fire Control Circuit A **308a** and/or Fire Control Circuit B **308b** cause their corresponding Capacitor Circuit **310a** or **310b** to rapidly discharge the energy stored therein via its corresponding Ordnance Module Interface **314a** or **314b** through the detonator(s) enclosed therein, thereby initiating the detonator(s). The Command Monitor **306** provides feedback to the control device on the whether the commands provided by the control device have been properly executed by the electronics module **102**.

FIG. **4A** is an isometric view of the ordnance module **104** of FIGS. **1A** and **1B** according to an illustrative embodiment of the invention. FIG. **4B** is a cross sectional view of the ordnance module **104** along its axis. Referring to FIGS. **4A** and **4B**, the ordnance module **104** includes a blast-resistant housing **402** with a female connector **404** at the proximal end and a detonating cord port **406** at its distal end (more clearly seen in FIG. **4B**) for holding a detonating cord **408**. A detonator **410** is located within the housing **402**.

The housing **402** is constructed of aluminum sufficiently thick to prevent the explosive force generated by detonation of the detonator **410** from substantially damaging an electronics module **102** to which the ordnance module **104** attaches. That is, the housing **402** is constructed to be sufficiently rugged that detonation does not damage the male connector of the electronics module **102** to a degree that it cannot mate with the female connector of another ordnance module **104** or damage the electronics (e.g., electronics components **300**) enclosed within the electronics module **102** to render them incapable of triggering such other ordnance module. In addition, in certain embodiments, the interior of the housing **402** is shaped to direct the explosive force of the detonator **410** away from its proximal end and towards its distal end and the detonating cord **408**. This further reduces the force impacting an electronics module **102**. In alternative implementations, other metals besides aluminum, or alloys of multiple metals may be employed without departing from the scope of the invention.

The interior of the housing **402** is coated with electrical insulation to prevent arcing, particularly at high altitudes. In one implementation, potting is used for insulation. In alternative embodiments, the insulation is provided by applying a conformal coating of Parylene and/or polyurethane or other suitable coating.

The female connector **404** is selected to mate with the male connector **204** of an electronics module **102**. As indicated above, in alternative implementations, the male and female connectors may be reversed such that the female connector extends from the electronics module **102** and the male connector extends from the ordnance module **104**. Referring back to the female connector **404**, the connector **404** includes receptacles for each of the pins of the male connector **404**. Multiple receptacles receive current from the electronics module **102** in parallel and multiple receptacles transmit current flow back to the electronics module **102** in parallel to achieve a low impedance connection. The wiring connecting the receptacles of the connector **404** to the detonator **410** are preferably made from a multiplicity of short strands of heavy gage wire connected in parallel. The female connector **404** also includes a threaded rotatable hex coupling nut **412**. The

ordnance module can then be easily and securely coupled to the electronics module by inserting the male connector **204** into the female connector **404**, followed by the user tightening the rotatable hex coupling nut **412** to secure the connection. While no tools are necessary for such a connection, a user may employ a hex coupling wrench to tighten the connection.

The detonating cord port **406** holds a detonating cord **408**. Preferably the detonating cord **408** is a flexible confined detonating cord, also known as an FCDC. The detonator **410**, is preferably an exploding foil initiator (or EFI), also referred to as a slapper detonator, though other electrically triggered detonators known in the art may be employed without departing from the scope of the invention. The explosive force of the detonator **410** may vary and is selected for the specific application as needed. Ordnance modules **104** with higher power detonators are constructed with thicker housings to increase their blast-resistance accordingly. The exact appropriate thickness will vary based on explosive power, shape of the housing, and other ordnance module parameters, and can be determined by one of ordinary skill in the art without undue experimentation.

Firing systems, such as those described in the FIGS. 1A-4B can be used for a variety of applications. They can be used in mining, excavation, demolition, munitions, or in other applications. For example, such firing systems may be used in triggering explosives that separate various stages of launch vehicles, such as rockets, during take-off. They may also be used to deploy payloads carried by such launch vehicles. Such firing systems are particularly useful in applications in which the electronics modules incorporated therein can be recovered post ordnance detonation, allowing them to be re-used. They are also useful in applications in which it is desirable to initiate multiple detonations in a serial fashion from a single electronics module. FIGS. 5-7, described, below, depict various methods of using the firing systems according to illustrative embodiments of the invention.

FIG. 5 is a flow chart of a method **500** of using a firing system, similar to that depicted in FIGS. 1A and 1B, though only having a single connector. Thus, the electronics module can only be connected to one ordnance module at a time. From a connectivity standpoint, single ordnance electronics module includes only a single fire control port, such as Fire A Input port **206**. The method **500** begins with providing the electronics module (step **502**) and connecting it to a control device with the appropriate cables.

Before proceeding, the control device may optionally initiate a diagnostic test of the electronics module (step **504**). To conduct a diagnostic test, a dummy ordnance module is connected to the electronics module. The dummy ordnance module includes a simulated load selected to match that of a detonator. It also includes an output back to control device. The control device analyzes the output of the dummy ordnance to determine if the electronics module is functional. If the electronics module fails the test, it is either replaced or repaired before proceeding.

A first ordnance module, such as ordnance module **104**, is then connected to the electronics module (step **506**). Upon instruction from the control device, the electronics module triggers initiation of the detonator enclosed in the ordnance module **104** (step **508**).

Before reusing the electronics module, optionally, a user may retest the electronics module (step **510**) to confirm that detonation of the first ordnance module did not damage the electronics module. If the electronics module fails the test, it is either replaced or repaired before proceeding. A second

ordnance module is then coupled to the electronics module (step **512**), which subsequently triggers its detonation (step **514**).

FIG. 6 is a flow chart of a second method **600** of using a firing system, such as the firing system **100** of FIGS. 1A and 1B. Method **600** provides for sequential initiation of two ordnance modules **104** that are connected at the same to the electronics module **102**. The method begins with providing the electronics module **102** (step **602**) and connecting it to a control device. Before proceeding, the control device may optionally initiate a diagnostic test of the electronics module **102** (step **604**). If the electronics module fails the test, it is either replaced or repaired before proceeding.

First and second ordnance modules **104** are then connected to the electronics module **102** (steps **606** and **608**). Upon instruction from the control device, the electronics module **102** triggers initiation of the detonator in only the first ordnance module **104** (step **610**). As the firing system is designed such that the detonation of the detonator does not render the electronics module **102** inoperable, the control device then instructs the electronics module to trigger initiation of the detonator in the second ordnance module **104** (step **612**). Optionally, the electronics module **102** may be tested again between initiation of the detonator in the first ordnance module and the detonator in the second ordnance module.

FIG. 7 is a flow chart of a third method **700** of using a firing system, such as the firing system of FIGS. 1A and 1B. Method **700** provides for simultaneous initiation of two ordnance modules **104** connected to an electronics module **102**. Steps **702-708** of method **700** are identical to method steps **600-608** of method **600**. In contrast to method **600**, in method **700**, the electronics module simultaneously initiates the detonators in both ordnance modules (step **710**).

The invention may be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The foregoing embodiments are therefore to be considered in all respects illustrative, rather than limiting of the invention.

What is claimed is:

1. A method of using a firing system:
  - providing an electronics module comprising firing electronics enclosed within a first housing;
  - coupling a first ordnance module to the electronics module, wherein
    - the first ordnance module comprises a blast-resistant housing enclosing a detonator;
    - the electronics module is coupled to the first ordnance module via a detachable connector extending away from the electronics module; and
  - triggering, by the electronics module, initiation of the detonator, wherein the blast-resistant housing of the first ordnance module prevents the resulting detonation of such detonator from damaging the connector extending away from the electronics module or the firing electronics.
2. The method of claim 1, comprising test firing the firing electronics prior to coupling the first ordnance module to the electronics module.
3. The method of claim 1, comprising, subsequent to initiation of the detonator in the first ordnance module, coupling a second ordnance module to the connector extending away from the electronics module; and triggering, with the firing electronics, initiation of a second detonator enclosed within the second ordnance module.
4. The method of claim 1, comprising coupling a second ordnance module to the electronics module via a second

connector extending away from the electronics module prior to triggering initiation of the detonator enclosed within the first ordnance module.

5. The method of claim 4, comprising triggering, by the electronics module, initiation of the detonator enclosed within the first ordnance module at substantially the same time as triggering initiation of a detonator enclosed within the second ordnance module.

6. The method of claim 4, comprising triggering, by the electronics module, initiation of the detonator enclosed within the first ordnance module subsequent to triggering initiation of a detonator enclosed within the second ordnance module.

7. The method of claim 1, wherein the detachable connector includes multiple male connectors, each with multiple pins reducing impedance in the connectors and carrying in parallel a triggering current to the ordnance module.

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